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AN EXPERIMENTAL FORECAST OF THE 1987 RAINFALL IN THE NORTHERN NORDESTE REGION OF BRAZIL

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1. Introduction

The ocean and atmosphere are linked through a number of physical processes at their interface. One aim of the Synoptic Climatology branch of the Meteorological Office in recent years has been to investigate the importance of large scale changes in sea surface temperatures to low frequency atmospheric variability in the tropics and the extra-tropics. Progress has been made possible by the creation of a quality-controlled global dataset of monthly sea surface temperature, which shows the sea surface temperature fluctuations over the present century in great detail (Bottomley et al, 1987). Empirical work has related recurring large scale sea surface temperature anomaly (SSTA) patterns to tropical atmospheric anomalies both near to and remote from the anomalous sea surface temperature development. Parallel experiments with the physically formulated Met Office 11-level global atmospheric general circulation model have been vital to this progress. When the ocean surface temperatures in the model are perturbed by observed amounts, the model develops tropical rainfall anomalies which tend to agree in some regions with observation to an encouraging extent. By June 1986, this type of work had yielded sufficiently positive results to justify issuing to African countries a forecast of Sahel rainfall based on statistical models; these related worldwide sea temperatures measured in the Northern hemisphere spring to Sahel rainfall in the immediately following summer (Folland, Palmer and Parker (1986), Folland, Ward, Parker and Colman (1986)). Since that time, other tropical regions that are prone to high interannual rainfall variability have been investigated in a physically-based search for prognostic relationships. A body of empirical and physical knowledge already exists relating N Nordeste rainfall to ocean-basin scale sea temperatures and their anomalies. We have been able to extend this work to produce forecasts for the N Nordeste which show good promise. The remainder of this document outlines our methods and reviews some model predictions for the March-May rainfall season in the N Nordeste of Brazil, with some indication of our confidence in this year's forecast.

2. Previous work

A variety of authors have published work relating N Nordeste rainfall to large scale SST and atmospheric circulation variations elsewhere. In particular, Hastenrath and Heller (1977) and Moura and Shukla (1981) established links between N Nordeste rainfall and sea surface temperatures. Namias (1972) found a statistical relationship between N Nordeste rainfall and the North Atlantic Oscillation, while others (eg Covey and Hastenrath, 1978) found El Nino to be important. Hastenrath, Wu and Chu (1984) synthesised existing knowledge on N Nordeste rainfall at that time to produce a multiple regression forecasting system using both atmospheric and oceanic predictors as variables. Our system makes use of patterns of sea surface temperature anomalies as the sole predictors. This may seem restrictive but the sea surface temperature anomalies are available in near real time, making them potentially useful in forecasting, and as indicated below they show useful potential on their own for predicting N Nordeste rainfall.

3. Forecasting system

The predictors are measures of the strengths of sea surface temperature anomaly (SSTA) patterns on the scale of major ocean basins. More specifically, the SSTA patterns in the Atlantic, Pacific and Indian Oceans are individually represented by eigenvector coefficients. The SSTA covariance eigenvector (EOF) patterns were formed for these three oceans separately using 1901-80 N hemisphere winter data. Each eigenvector coefficient effectively measures the extent to which the eigenvector pattern is present in the observed SSTA pattern. A November to January average and February SSTAs have been used to form the predictor eigenvector coefficients. Linear discriminant analysis is used to establish relationships between rainfall (mainly March-May) and SSTA patterns (in November-January and February) over a long training period (for details of the method see Maryon and Storey (1985), Folland and Woodcock (1986), Folland, Parker, Ward and Colman (1987)). This year's SSTAs (ie those for November 1986 to January 1987 and February 1987) are then fed into the statistical equations to produce a forecast of the 1987 rainfall. The forecast is expressed in the form of a probability distribution of rainfall amounts; these amounts are currently divided into 5 climatologically equiprobable rainfall categories, eg a forecast may have the form:

category	forecast probability	climatological probability
very dry	30%	20%
dry	20%	20%
average	20%	20%
wet	15%	20%
very wet	15%	20%

4. Rainfall data

Two different rainfall series have been used to establish forecast relationships between SSTA patterns and rainfall:

a. A March-April standardised series for the N Nordeste compiled by Hastenrath (Lamb, Peppler and Hastenrath, 1986) (see Figs 1 and 2). The series covers the years 1913-1984.

b. A series for March-May created by ourselves from standardised data for Fortaleza and Quixeramobim (situated in the far north of the region, see Figure 1). This is a slightly longer series including the years 1901-1986.

Using two different rainfall series in this way produces two distinct sets of models; one forecasting for March to April N Nordeste rainfall, the other forecasting for Quixeramobim and Fortaleza rainfall in March to May.

5. 1987 forecasts

Run A) 10 forecasts of March to April 1987 rainfall over the N Nordeste (based on Hastenrath's series). Mean forecast probability distributions are shown below. The forecast models used here are based on five different training periods:

1913-1945
1913-1982 (The three eigenvector patterns used
1913-1986 as predictors are discussed below.)
1946-1982
1946-1986

November to January and February SSTAs were used separately to form predictor coefficients for each of the five training periods.

Forecast for March-April 1987 N Nordeste

sea temperatures observed in		quint 1 very dry	quint 2 dry	quint 3 average	quint 4 wet	quint 5 very wet
Nov 1986-Jan 1987	P=	0.57	0.19	0.13	0.07	0.04
Feb 1987	P=	0.61	0.18	0.15	0.03	0.02

Run B) 10 forecasts of March-May 1987 rainfall for the Quixeramobim and Fortaleza standardised series. Mean forecast probability distributions are shown below. The forecast models used are based on five different training periods:

1901-1945
1901-1982 (The three eigenvector patterns used
1901-1986 as predictors are discussed below.)
1946-1982
1946-1986

The two predictor SSTA data periods were used, as above, with each training period.

Forecast for March-May 1987, combined Quixeramobim/Fortaleza series

sea temperatures observed in		quint 1 very dry	quint 2 dry	quint 3 average	quint 4 wet	quint 5 very wet
Nov 1986-Jan 1987	P=	0.45	0.13	0.18	0.23	0.01
Feb 1987	P=	0.45	0.18	0.14	0.18	0.05

Three SSTA EOF patterns were found to consistently affect N Nordeste rainfall:

a. An SSTA EOF representing the 'El Nino' pattern in the Pacific (Figure 3a).

b. A pattern associated with the North Atlantic Oscillation (a low frequency weather pattern covering much of the N Atlantic) with bands of anomalies of opposite sign in the tropical Atlantic N and S of the equator (Figure 3b).

Note that Palmer (1985) shows that N Nordeste rainfall (March-May approximately) may be linked to the N Atlantic Oscillation (NAO) in the previous N Hemisphere winter, but that the NAO does not seem to be

directly associated with SSTAs in the Tropical Atlantic south of the equator.

c. Another Atlantic pattern, which had anomalies of the same sign in the N and S Tropical Atlantic but with greater strength south of the equator (Figure 3c).

We now review some tests of the performance of the forecasts on independent data and indicate approximate levels of confidence in the 1987 forecasts.

6. Performance of the forecasts on independent data and confidence in the 1987 forecast

The performance of the models in independent testing periods appears encouraging (see Tables 1, 2). When models consisting of the three EOFs discussed above have forecast a very dry year in independent historical testing periods, N Nordeste rainfall was observed to be dry or very dry on over 70% of occasions, compared to a chance level of 40%.

For 1987, 19 out of the 20 models predict that this year will be very dry (quint 1), with both November-January SSTAs and February SSTAs suggesting a dry year is most likely. When this has been the case in the previous El Nino winters we have studied, the observed rainfall was indeed categorised as very dry. In cases where November-January SSTAs predict very dry but, because of a decline in El Nino, February SSTAs predict wet or less dry, the observed rainfall did indeed turn out not to be quint 1. Persistence of El Nino through to February is by itself no guarantee of a very dry rainy season in the N Nordeste. The statistical models show skill in choosing the El Nino years which are likely to be dry, using the relative strengths of the anomaly patterns in the Pacific and the Atlantic to discriminate between wet and dry El Nino years. These observations should be viewed with caution because the number of El Nino years in the historical data period is not sufficient to enable such detailed empirical conclusions to be made with high confidence.

Table 1

Contingency Table for forecasts of Hastenrath rainfall series using 1913 to 1945 training data and 1946-1984 testing data, and February SSTAs (39 forecasts)

FORECAST QUINT	OBSERVED QUINT 1	2	3	4	5	1987 forecast P
1	6	3	0	1	0	0.69
2	1	1	1	0	1	0.06
3	1	0	2	2	3	0.22
4	0	1	4	2	4	0.01
5	0	1	2	0	3	0.03

Table 2

Contingency Table for forecasts based on Hastenrath series (1913-1945 training, 1946-1984 testing, and 1946-1986 training, 1913-1945 testing data) and Quixeramobim/Fortalexa series (1901-1945 training, 1946-1986 testing and 1946-1986 training, 1901-1945 testing data): predictions from all runs A) November-January, B) February (2 x 158 forecasts)

A) November-January

FORECAST QUINT	OBSERVED QUINT 1	2	3	4	5	1987 forecast P
1	17	8	5	3	3	0.62
2	5	7	8	4	3	0.12
3	7	10	7	10	3	0.16
4	3	3	9	4	12	0.08
5	1	1	4	12	9	0.02

chi-squared = 54.8 sig at <0.1%
assuming 4 x 4 = 16 df

B) February

FORECAST QUINT	OBSERVED QUINT 1	2	3	4	5	1987 forecast P
1	22	8	4	4	1	0.53
2	3	11	7	3	4	0.15
3	7	2	6	5	5	0.17
4	1	3	8	12	12	0.10
5	0	5	8	9	9	0.04

chi-squared = 67.8 sig at <0.1%
assuming 4 x 4 = 16 df = 0

It is clear that the February forecasts are better if the forecast is for dry conditions.

The continued forecast of very dry conditions for 1987 is due to the continued strength of El Nino, whose EOF coefficient actually rose in February, and to Tropical Atlantic SSTAs being too weak to diminish the dry influence of El Nino.

7. Conclusion and caveats

Although we have some confidence in a forecast of a very dry or at least a dry year in the N Nordeste, the work is still at an early developmental stage. At the present time our models forecast the correct rainfall category about 33% of the time compared to a chance value of 20%. However for extreme forecasts (Tables 2A and 2B) the value is 41%. The chance of a major error in this forecast (quint 1 forecast and quints 4 or 5 observed) is, from tables 2A and 2B about 15% compared to a chance level of 40%. We recommend, though, that the forecasts based on February data are marginally the more reliable. Another point is that we do not strictly forecast a very dry year; it can be seen that although category 1 (very dry) is by far the most probable, its probability using February data for the N Nordeste as a whole is still only 61%. However the probability that it will be wet or very wet is low (5%) compared with the probability that the season will be dry or very dry (79%).

Thus it is suggested that the likelihood of very dry or dry conditions during this year's rainy season is high but given the early stage of the research, the forecast should be viewed with great caution.

8. References

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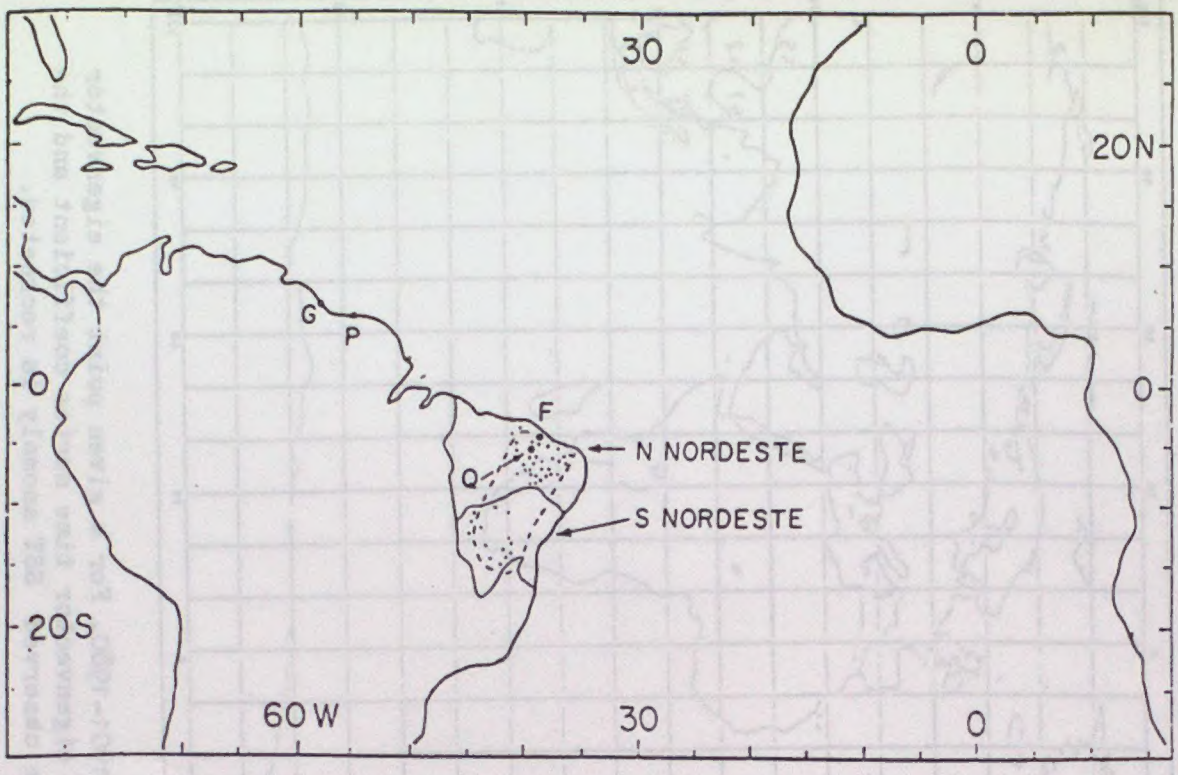

Figure 1. Orientation map. Thin solid lines delineate the Northern and Southern Nordeste, and broken line the region of Nordeste with annual rainfall below 800mm. Dots denote rainfall stations, with letters identifying Fortaleza (F),Quixeramobim (Q),Georgetown (G),and Paramaribo (P). Source: Hastenrath et al. (1984).

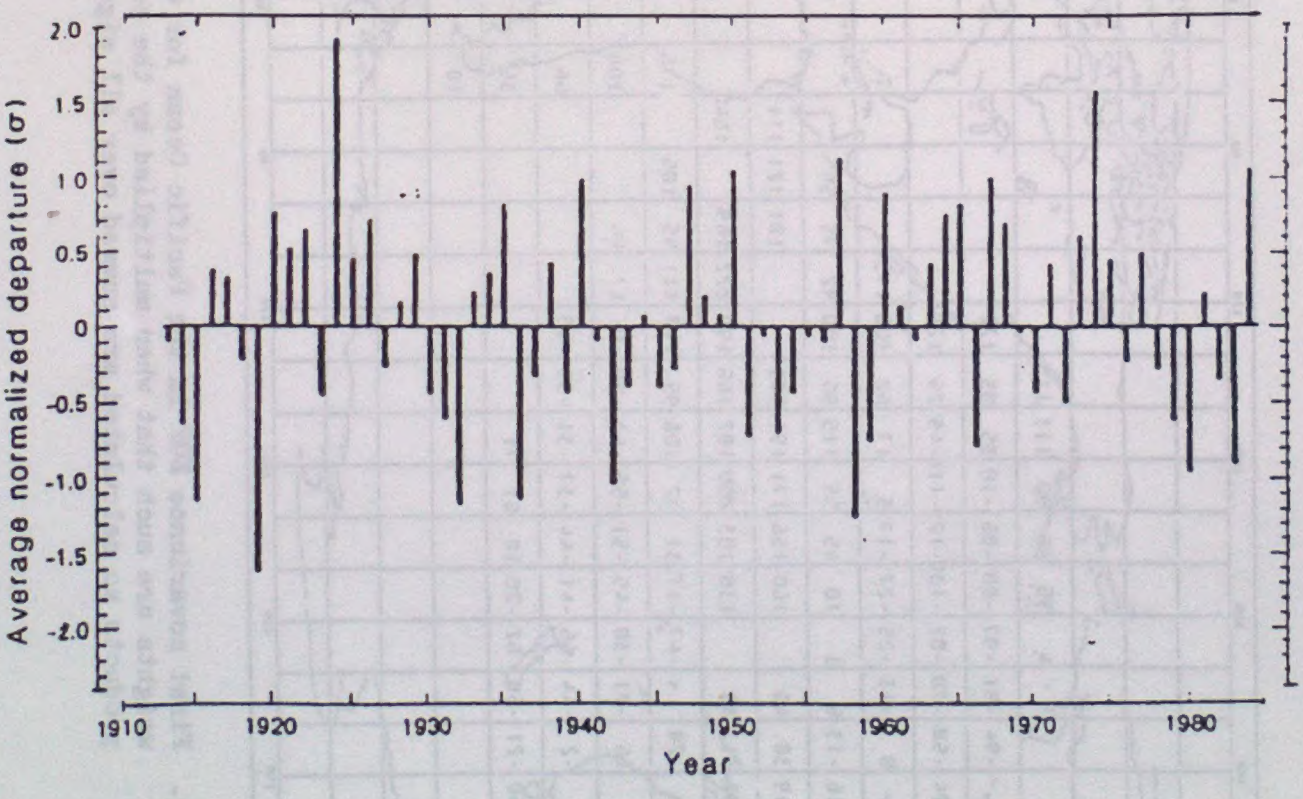

Figure 2. **Standardised March - April rainfall in the Northern Nordeste. (From Lamb, Peppler and Hastenrath, 1986).**

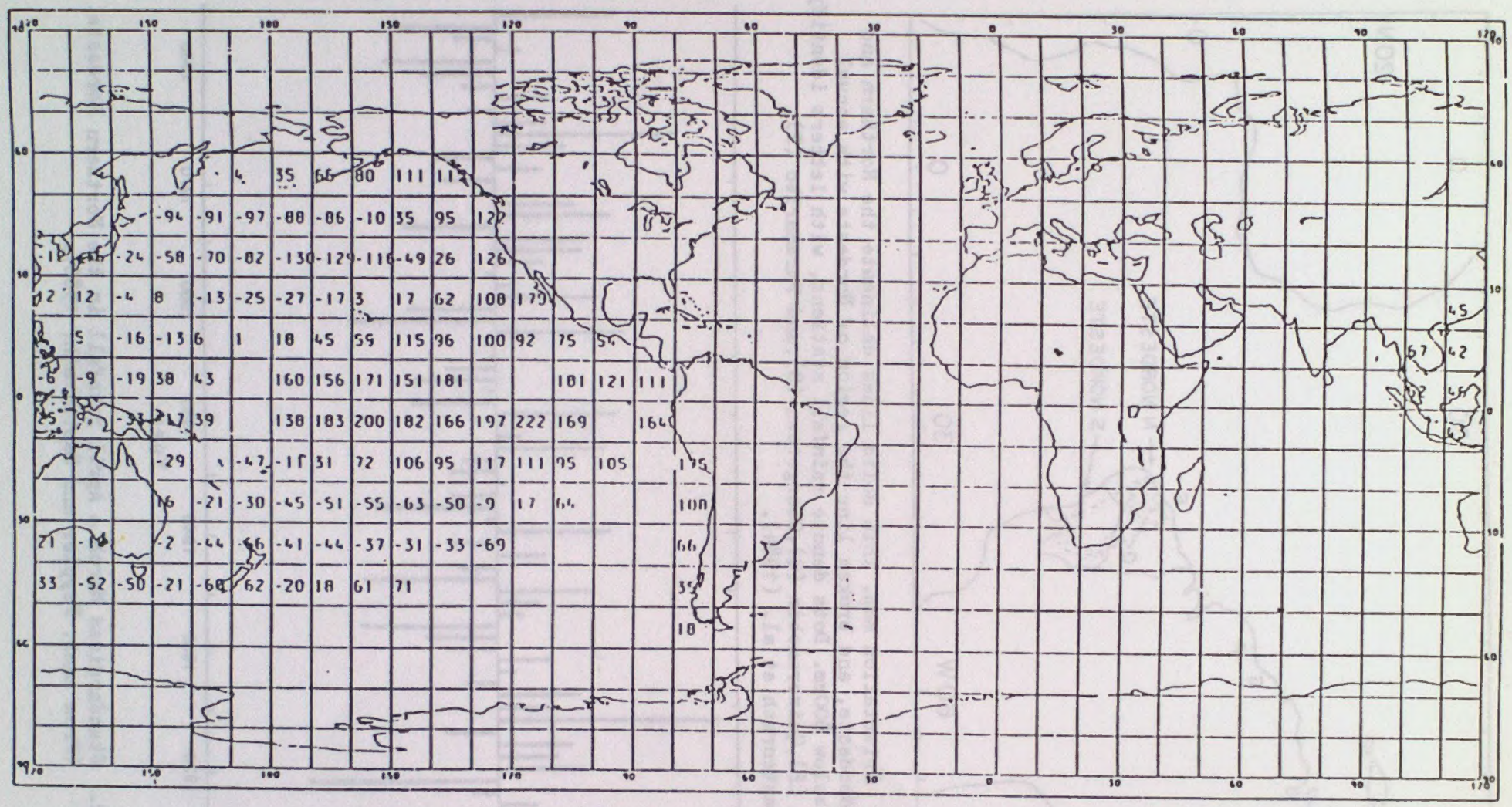

Figure 3a. First covariance EOF in the Pacific Ocean for winter data 1901-1980. For a given point the eigenvector weights are such that when multiplied by the corresponding eigenvector time series coefficient and the products so calculated are summed over all eigenvectors the observed SST anomaly is recreated.

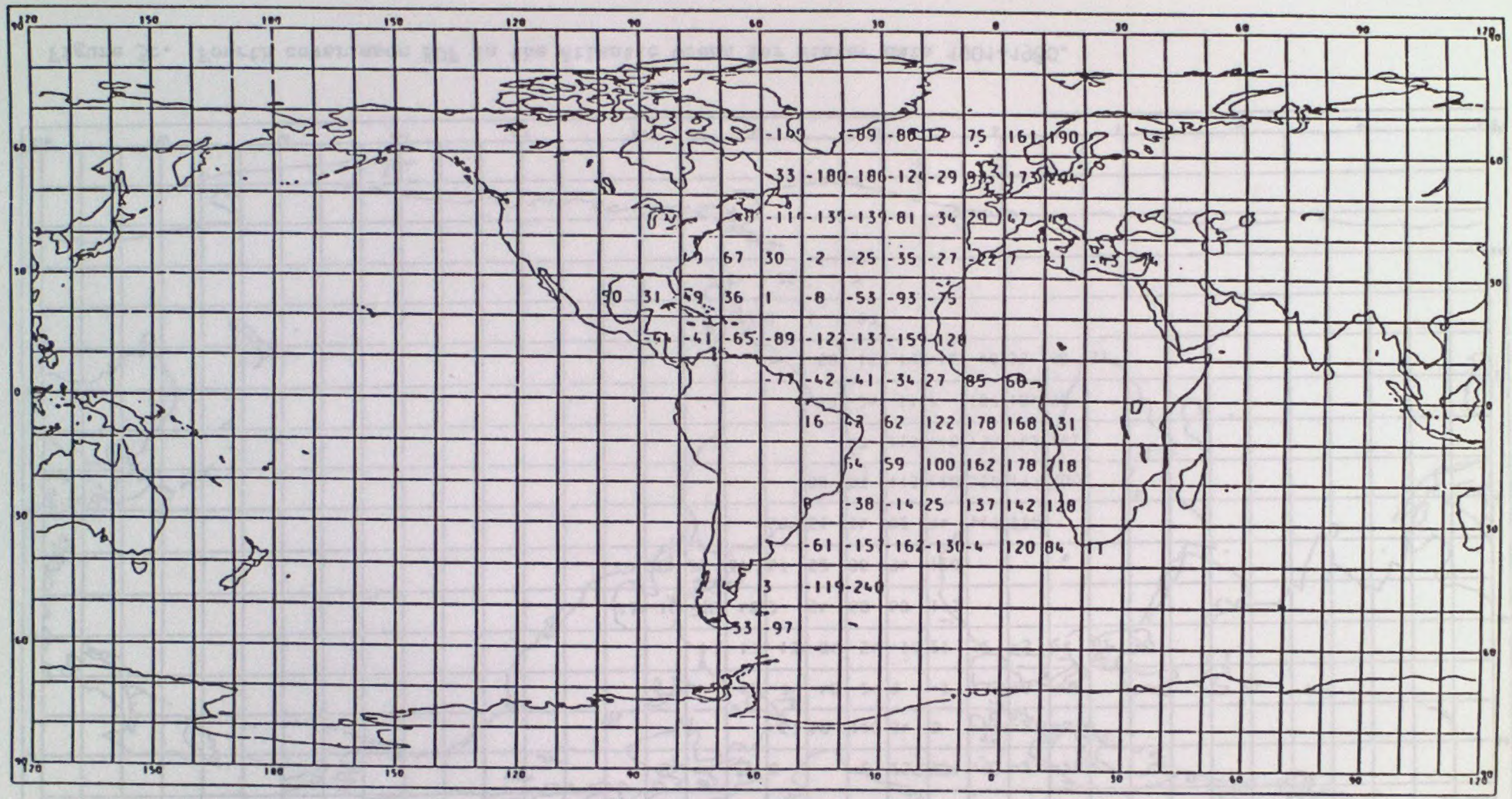

Figure 3b. Third covariance EOF in the Atlantic Ocean for winter data 1901-80.

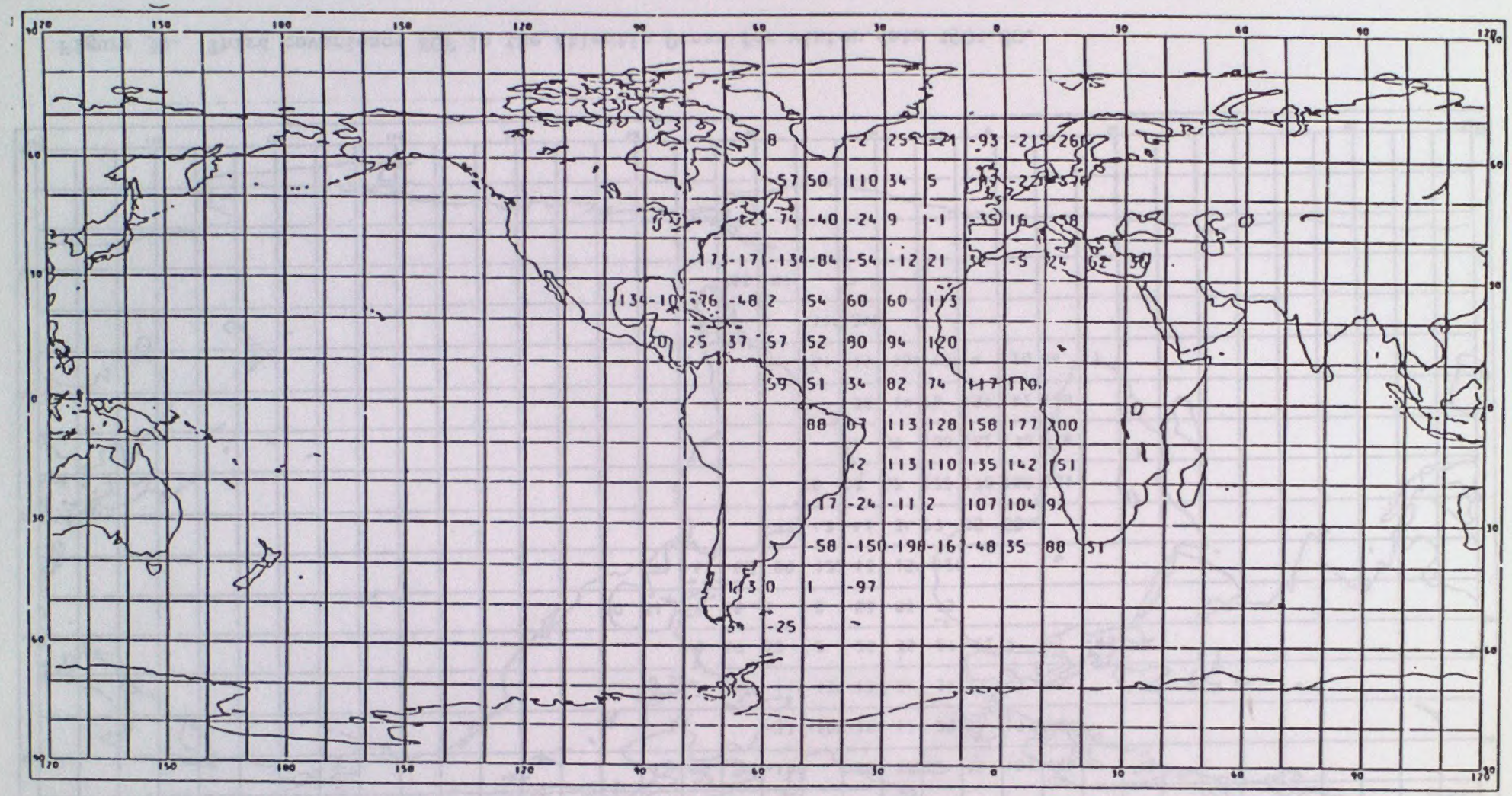

Figure 3c. Fourth covariance EOF in the Atlantic Ocean for winter data 1901-1980.

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